Vehicular Ad-Hoc Networks: Introduction, Standards, Routing Protocols and Challenges

Vinita Jindal[1], Punam Bedi[2]
[1,2] Department of Computer Science, University of Delhi
Delhi, India

Abstract

The development in the field of Intelligent Transportation System (ITS) is growing exponentially with the advancement of Vehicular Ad-hoc NETworks (VANETs). Vehicular networks have gained notable attention among the researchers from both industry and academia due to major research going in the era of smart cities. There exist many standards for wireless access in VANETs such as 2G, 2.5G, 3G, 4G, DSRC, WAVE and WiMAX. Further existing topological and geographical MANET routing protocols are also used to help the vehicles in making the routing decision for dynamic and highly mobile environment. There also exist some routing protocols specifically designed for the vehicular environment. The paper discusses existing routing protocols that are most commonly used by VANETs as per best of our knowledge, with their details and the problems associated with these protocols. Some open challenges and possible direction for future research in the field of VANETs are also included in the paper.

Keywords: *Ad-Hoc Networks; Vehicular Ad-hoc NETworks (VANET); Mobile Ad-hoc NETworks (MANET); Intelligent Transport Systems (ITS); DSRC; Routing in VANET.*

1. Introduction

Intelligent Transport Systems (ITS) make use of communication, network and information technology to improve the mobility, quality, comfort and safety in smart cities [1]. For the development of ITS, Vehicular Ad-Hoc NETwork (VANET) is considered as a backbone for all applications and attracted many researchers from both industry and academia all over the world [2], [3]. VANET has the potential to improve vehicle safety on the roads, efficiency of traffic and comfort to commuters [4]. In VANETs, the information exchange occurs among vehicles not only in an ad-hoc based Vehicle-to-Vehicle (V2V) communication but also in a Vehicle-to-Infrastructure (V2I) and Infrastructure-to-Infrastructure (I2I) communication as shown in Figure 1. Various roads with moving vehicles are shown in the figure along with roadside infrastructure used for I2I or V2I communication. In order to utilize the full potential of VANETs, the fixed infrastructure plays a major role. It helps in exchanging of information among vehicles and infrastructure about any danger situations in order to reduce the inconvenience to commuters.

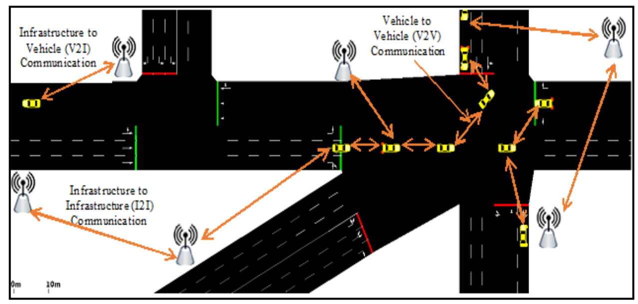


Fig. 1 Various Types of Communication in VANETs

VANETs can be utilized for a large range of safety, non-safety and comfort applications. These applications include a kind of value added services such as enhanced navigation, automated toll payment, traffic management, vehicle safety, location-based services such as finding the cafeteria, motel and/or guest house, closest fuel or air filling station and various infotainment applications such as offering Internet access to download movies or songs etc. [3], [5]. In VANETs, four basic types of messages can be exchanged among vehicles and infrastructures as given below:

- **Emergency and warning messages:** Emergency messages can include any type of critical emergency such as accidents, passing of ambulance, fire or police vehicles. Warnings regarding repair on roads, traffic congestion come under the category of warning messages.
- **Inter-personal messages:** Messages related to the profile of a driver and other passengers on the vehicle come under this category.
- **Routing and Safety messages:** This category comprises of messages about the information used by various routing protocols and current driving conditions. Safety messages take the information related to vehicle's speed, position, direction and identity etc. for safe communication.
- **Information and Entertainment messages:** These messages are related to the resources and services available on the roadside infrastructure, and/or the

services offered by other participating vehicles on the road. The types of messages in this category are the information about nearby food point, gas or petrol filling stations, nearby points of interest and so on.

This paper discusses the present state-of-art in the field of vehicular ad-hoc networks discussing their evolution from the wireless ad-hoc networks. In the paper, we present almost all aspects related to the field of VANET in order to help researchers and developers in understanding the main features, standards and protocols in one document. There exist many papers in the literature containing either VANET standards or routing protocols or the combination of both. To the best of our knowledge, VANET standards and routing protocols altogether are not discussed in a single paper in the literature. In this paper we are compiling both at the same place to add the value in the research. The remainder of the paper is structured as follows: next section discusses the classification of wireless ad-hoc networks with the overview of VANETs and their comparison with MANETs. Standards for wireless access in VANETs are further illustrated in terms of cellular access, DSRC, WAVE and WiMAX in section 3. Section 4 describes some routing protocols specially designed for VANETs with other existing protocols for MANETs that are used in the domain. The challenges and future perspectives are discussed in section 5. Finally summary of the work in section 6 concludes the paper.

2. Evolution of VANETs

In Vehicular ad-hoc networks, the term "Ad-hoc" is a Latin word with the meaning "for this purpose" [6]. Here, the network consists of multiple nodes that are connected through wireless links. In ad-hoc networks the links may connect or disconnect very frequently. So, in order to manage the robust, reliable, efficient, timely and scalable ventures in ad-hoc network, dynamic restructuring needs to be handled by the underlying network [7]. For this, the network should send the information through other nodes of the system to perform the communication among any pair of nodes. A wireless ad-hoc network is an ad-hoc network in which all communication links are wireless. The main features of a Wireless Ad-hoc NETwork (WANET) are absence of pre-existing infrastructure and fixed base stations; transmission within link coverage and mobile nodes with dynamic connections.

2.1 Classification of wireless ad-hoc networks

Wireless ad-hoc networks [8] being persistent and economical can be widely used in emergency situations like military conflicts or natural disasters because of their minimal configuration requirement and quick deployment. Wireless ad-hoc networks are further evolved into three subcategories, according to their use in various applications as shown in Figure 2.

The three categories of Wireless ad-hoc networks (WANETs) are:

- Wireless Sensor Networks (WSNs)
- Wireless Mesh Networks (WMNs)
- Mobile Ad-hoc NETworks (MANETs)

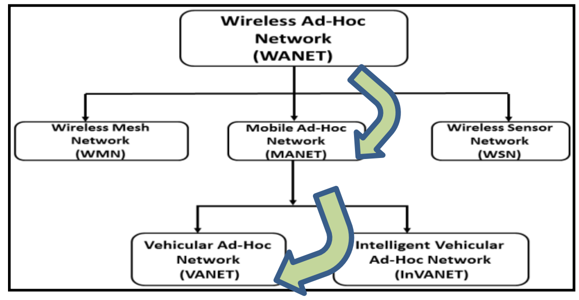


Fig. 2 Evolution of VANETs

Figure 2 depicts that VANET is a subclass of MANET that further a subclass of WANETs. VANET are formed with vehicles as nodes in contrast to MANET that uses mobile phones/laptops. A Mobile Ad-hoc NETwork (MANET) is an infrastructure-less and self-configuring network of mobile nodes coupled through wireless links. Every node in a MANET can move independently in any direction, and hence links of that node with other nodes in the network may change very frequently.

2.2 Overview of VANET

In Vehicular Ad-Hoc NETwork (VANET) moving vehicles are considered as nodes and the distance between them on the roads is considered as edges in the network. Each vehicle can accept and transfer the messages with other vehicles or road infrastructure through the wireless medium [9]. All participating vehicles can be considered as a wireless nodes or routers, allowing them to connect and communicate in the range of approximately 100 to 500 meters and forms a network [1], [10]. When a vehicle falls out of the signal range, it will be dropped out of the network. Any other vehicles can join the network, when it comes in the signal range of the existing vehicles in the network [11]. These vehicles are furnished with advanced wireless communication devices known as On Board Units (OBUs) and have no base stations assigned to them [12]. These OBUs are responsible for V2V and V2I communications.

Intelligent Transportation System (ITS) is the major application supported by vehicular ad-hoc networks. Another important application of VANETs is to deal with safety. For example, if a road accident is detected by some vehicle then, this information about the accident must be forwarded to other neighboring vehicles present in the system. The requirement of safety messages is that they must be delivered to each neighboring node without delay i.e. within limited time. If a single event-driven message is lost or safety message is delayed, it could end in loss of life [13]. ITS uses the WAVE standard for reducing inconvenience and avoiding danger situations like prevention and/or detection of various accidents [14]. ITS can also be used for distributing information and data about the road maintenance, weather forecasts and road conditions along with emergency notifications.

The usage of Advanced Driver Assistance System (ADAS) is possible through VANETs. ADAS uses ad-hoc communication for delivering driver assistance efficiently along with the safety of the vehicle. The data obtained from the roadside units and other vehicles is used for the communication of messages. VANET applications can be categorized into four main classes: Safety (time-critical and life-critical applications), Traffic Management (provide traffic information, prevent traffic jams), Enhanced Driver Comfort and Maintenance and is described below:

- **Safety Applications:** Warning for violation of traffic signals, stop sign and intersection collision; warning for emergency vehicle approaching, breakdown and wrong way driver; and tracking of stolen vehicle etc. are included in this category.
- **Traffic Management Applications:** These applications comprises of area access control, traffic flow control, electronic toll payment and rental car processing etc. for the free movement of the traffic on the roads.
- **Enhanced Driver Comfort Applications:** The applications under this category include enhanced route guidance and navigation, parking spot locator, point-of-interest notification and map download/update/GPS correction etc. for the driver's assistance while on move.
- **Maintenance Applications:** These applications include wireless diagnostics, safety recall notice and information about software update/flashing etc.

2.3 Comparison of MANETs and VANETs

Mobile Ad-hoc NETwork (MANET) is a collection of nodes that are mobile and does not use fixed infrastructure. The nodes in a MANET may connect among themselves in a decentralized and self-organizing manner. Nodes that are part of the MANET, but beyond each other's wireless range communicate using a multi-hop route through other nodes in the network. When the mobile nodes are replaced with vehicles then the network in consideration becomes a Vehicular Ad-hoc NETwork (VANET). The main distinguishing feature of VANET is that at any point of time, the number of nodes is very large in VANET and these nodes move with very high average speed [15].

In VANET, due of the high mobility and fast speed of vehicles, there is a quick and frequent change in the network topology. In VANET, the vehicles can move only on pre-set roads. They do not have any constraint in terms of power or data storage [16]. Moreover, it is possible for a vehicle to obtain its current geographic position by GPS or any other location retrieval service that helps in keeping time synchronization with the network. VANETs have many advantages over the traditional MANETs with respect to various parameters [17], [18]. VANET find out to be more expensive due to higher network bandwidth and broad range for communication in terms of both installation as well as maintenance but they provide high reliability in the network as compared with mobile ad-hoc network. Nodes of mobile network can be smart phone, laptops etc. whose lifetime depends on the battery of the resource whereas nodes of vehicular network are vehicles whose lifetime depends upon the vehicle's life. In MANETs attribute-based addressing with ultrasonic devices is used while in VANETs location-based addressing with GPS devices is used. All the difference between MANET and VANET are given in Table 1 below.

3. Standards for Wireless Access in VANETs

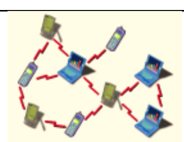
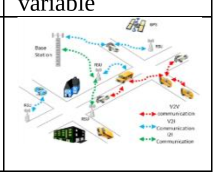
Standards simplify the development of new products and help in comparison of competing products. There are various wireless standards available to provide the radio access required by the vehicles in order to communicate via Vehicle-to- Vehicle communication, Vehicle- to-Infrastructure communication or Infrastructure- to-Infrastructure communication respectively. The main aim of these communication standards is to improve road safety, traffic efficiency and to provide driver's and passenger's ease by enabling a set of comfort applications.

As per best of our knowledge, none of the earlier researchers compile all the standards with inclusion of 4G in cellular access at one place. In [2] author has presented only DSRC and WAVE standard. Authors in the paper [19] have referred all the four types but 4G is missing in their work as well. In this paper, we surveyed all the available standards and combine it with the emerging 4G technology to give more insight of the area. The main wireless access technologies used in VANETs are cellular access i.e. 2G/2.5G/3G/4G, DSRC, WAVE and WiMAX that are described in Table 1.

3.1 Cellular access in Vehicular Environment (2G/2.5G/3G/4G)

The concept of the cellular access is based on the reuse of the limited frequency available for the services. Global system for mobile (GSM) communication is the oldest cellular system standard that provides a data rate maximum up to 9.6 Kbps. It was developed in Finland in 1991 also known as a second generation (2G) cellular service [1]. GSM makes use of both time division multiple access (TDMA) and frequency division multiple access (FDMA) schemes. General packet radio service (GPRS) also known as 2.5G standard, an extended version of GSM was developed in 2000 by the European Telecommunications Standards Institute (ETSI) to assist the efficient data transmissions at high bandwidth with maximum data rate up to 170 Kbps [12]. But GPRS failed to transmit a multimedia data at a high data rate. This led to the development of 3G also known as universal mobile telecommunication system (UMTS) in 2008; 3G is the evolved version the high-speed downlink packet access (HSDPA) developed in 2005, that can provide a data rate of maximum up to 2 Mbps. Another comparable cellular system is the CDMA 2000 which can provides data rate up to 3 Mbps for downlink and 1.8 Mbps for uplink respectively [17]. These two standards were not the part of GSM, thus GSM association provides the standards for cellular networks for providing high speed continuous data transfer rates.

Table 1. Comparison of MANETs and VANETs

Parameters	**MANET**	**VANET**
System Production cost	Cheap	Expensive
Reliability on the network	Medium	High
Range of communication	Up to 100m	Up to 500m
Mobility of nodes in network	Low	High
Mobility pattern of nodes	Unpredictable or irregular motion	Regular or periodic motion
Bandwidth of network	Up to 100 kps	Up to 1000 kps
Multi hop routing support	Available	Weakly available
Addressing scheme used in network	Attribute-based addressing	Location based addressing
Geographical Position acquirement	Using ultrasonic devices	Using GPS devices
Lifetime of nodes	Depends on resource power i.e. battery	Depends on vehicle lifetime
Density of nodes	Sparse	Dense and frequently variable
Diagrammatic representation		

Now days, the cellular communication standards have further emerged from 3G to 4G. The aim of 4G is to improve the high data transfer rate with mobility. 4G is also known as LTE standard that was developed in North America in 2010. It is predicted that the support of faster data transfer and extreme mobility support along with smooth handoff across heterogeneous networks can be obtained using 4G technology. However, at present, we have not found any literature indicating that 4G is indeed fulfilling all of these aspects. The main motive behind using the cellular system is to make use of the existing infrastructure. But in the cellular environment disadvantage is of high delay or latency due to the involvement of base stations. This issue has been taken care by DSRC by eliminating the need of the base station for communication.

3.2 Dedicated Short Range Communication (DSRC)

Dedicated Short Range Communication (DSRC) is developed in Europe and Japan in 2003, to support mainly Vehicle-to-Vehicle and Vehicle-to-Infrastructure communications. It is a short to medium range communication service based on IEEE 802.11p standard, which in turn is derived from IEEE 802.11a standard [4]. The aim of DSRC is to support low overhead operations in communication [12]. These communications may include traffic information, accident information, road conditions, inter-vehicle safety messages, toll collection, drive through payment and so on. DSRC is majorly used during communication for providing high data transfer with low communication delay or latency.

DSRC is a licensed but free spectrum. It is given free of cost as FCC does not charge its spectrum usage, but to restrict the usage of the spectrum for avoiding the congestion; it needs to be licensed [19]. For example, the use of specific channels and all radio stations should conform to the standard laid by FCC [4]. The DSRC spectrum is divided into seven channels. Each channel is 10 MHz wide. These channels are divided into one control channel and six service channels. Control channel is responsible for broadcasting high-priority messages and management data. Service channels are switched to monitor the control channel and transferring other data. There are different DSRC standards exists in literature used by various countries like USA, EUROPE and JAPAN [20]. These standards are differ in type of communication, radio frequency band used for communication, number of channels and their separation, data transmission rate, coverage and their modulation.

In USA and Europe, Half-duplex communication is being used for both OBU and RSU while in JAPAN, OBU uses the Half-duplex and RSU uses the full-duplex communication. Band for radio frequency is 5.9 GHz with 75 MHz bandwidth in USA, 5.8 GHz band with 20 MHz and 80 MHz bandwidth respectively in Europe and Japan. There are 7 channels with 10MHz and 5 MHz frequency for channel separation respectively in USA and Japan while Europe has 4 channels with 5MHz frequency for channel separation. The data can be transmitted at the rate of 3.27 Mbps with OFDM in USA, 250-500 Kbps and 1-4Mbps with 2 ASK or 2 PSK in Europe and Japan respectively. The network coverage provided by DSRC in USA, Europe and JAPAN is 1000m, 15-20 m and 30 m respectively.

3.3 Wireless Access in Vehicular Environment (WAVE)

Wireless fidelity (Wi-Fi) or Wireless local area network (WLAN) is used to provide wireless access in Vehicular networks to enable Vehicle-to-Vehicle communication or Vehicle-to-Infrastructure communication [21]. WLAN system has less delay or latency but the use of wireless local area network requires additional infrastructure such as wireless adapters and wireless routers that incurs an additional cost for its usage. IEEE 802.11 standards are used to provide the wireless connectivity [22]. Wireless access in a vehicular environment (WAVE) is the standard obtained by combining the whole DSRC protocol stack that includes both IEEE 802.11p and IEEE 1609 standards [1]. The disadvantage of using the traditional IEEE 802.11 in vehicular communication is the overhead generated at the significant rate. For example, to ensure timely vehicular communication, fast data exchanges are required. To address all these challenges, DSRC is combined with IEEE 802.11 standard to become a new standard as IEEE 802.11p, which further combines with IEEE 1609.x to form a universally accepted standard called Wireless Access in Vehicular Environments (WAVE) [12]. The protocols in IEEE 1609/802.16e standards are described as below.

IEEE Standard 1609 defines the communication model, security mechanism, management structure, physical access and overall architecture for wireless communications for basic components (RSU, OBU and WVE interface) in the vehicular environment [23]. IEEE Standard 1609.1-2006 enables the WAVE applications interoperability by describing the major components of its architecture, and further defines storage message formats and command [24]. IEEE Standard 1609.2-2006 describes various security services for the management of WAVE and provides application messages to avoid attacks like spoofing, replay, eavesdropping and alteration [25]. IEEE Standard 1609.3-2007 specifies routing services and addressing mechanism for WAVE system to enable multiple stacks of upper/lower layers above/below WAVE networking services, secure data exchange, defines WAVE Short Message Protocol (WSMP) as an alternative to IP for WAVE applications [26]. IEEE Standard 1609.4-2006 describes the enhancements made in Media Access Control Layer of 802.11 to support WAVE [27]. IEEE Standard 802.16e enables interoperability among various multi-vendor broadband wireless access products [28].

WAVE standard describes both stationary and mobile devices. Either of Road Side Unit (RSU), a stationary device and On Board Unit (OBU), a mobile device can be a provider or a user of services. The WAVE standard defines applications that resides on the RSU but is aimed to provide access to OBU by multiplexing the requests. It uses Orthogonal Frequency Division Multiplexing (OFDM) to split the signal into several narrowband channels and provide a data payload communication capability of 3, 4.5, 6, 9, 12, 18, 24 and 27 Mbps in 10 MHz channels [4].

3.4 WiMAX

WiMAX (worldwide interoperability for microwave access) is a modification of the standard IEEE 802.16e to provide a high data rate. WiMAX offers a wide transmission range, high quality of service and reliable communication standards that makes it suitable for all applications requiring the special features such as multimedia, video and voice over internet protocol (VoIP). It uses IEEE 802.11 standard for fixed infrastructure and IEEE 802.16 standard for mobile users.

WiMAX can fill the gap between cellular and WLAN standards [4], [17]. Here, the underlying fixed infrastructure makes use of cellular gateways and WLAN provides the wireless network access to all the moving nodes in VANET. WiMAX standard can work in the range of up to 10 km with one to many links at the data rate maximum up to 20 Mbps in the frequency band of 2.45 MHz with the support of all the three V2V, V2I and I2I communication in vehicular environment [1].

4. Routing in Vehicular Networks

Routing refers to a process through which a source node finds a route for reaching the destination node in underlying network. This work is done by routing protocols by gathering necessary information for the selection of routes between any two nodes. The main function of routing protocols is to establish a route, forwarding decision and maintaining routing information in routing tables. There can be many routes at the same time between the pair of source and destination nodes. Which route is to be chosen among many is the decision made by the routing algorithms [29], [30]. The selected route is generally the optimal with minimum congestion [31]. Vehicular networks possess different features from the classical networks. Here, mobility of vehicle is limited by the roads, movement of other vehicles and traffic rules [12]. Any vehicle can join the network or leave the network when it comes in the range or go out of the range of the network. High mobility of nodes in VANETs leads to frequent network disconnections and partitioning. Moreover there can be a case when there is no dedicated path between source and destination at the time of sending the message. These issues make conventional routing algorithms inappropriate for vehicular setup which becomes a challenge for researchers. Thus there is a requirement of protocol specific to the vehicular environment to accommodate the huge number of vehicles that participate in VANET communication [32].

There are several different classifications for vehicular routing protocols [21], [29], [30], [32], [33], [34]. However, we divide them into five categories: topology-based, geographical or position-based, opportunistic, information dissemination and interference-aware routing protocols. Topology-based routing protocols are the typical kind of wireless routing protocols that use information about the network links to perform packet forwarding [1]. In Geographical or position-based protocols, packet forwarding is primarily based on the position of the destination and that of its one-hop neighbors [4]. The major difference between topology-based protocols and position-based protocols is about their forwarding techniques and the strategy of recovery they use in case of failure. Topology-based protocols use wireless multihop forwarding technique, while position-based routing protocol use heuristic techniques for forwarding in the network. In case of failure, strategy of recovery used by the topology-based protocol is multihop forwarding while carry forward approach is being used by the position-based protocols [35]. These protocols neither exchange link-state information nor maintain established routes. Opportunistic routing protocols take into account intermittent connectivity that can happen, especially in low-density networks. Protocols for information dissemination aim to efficiently disseminate information, which is essential to several vehicular network applications. Unlike the other kinds of vehicular routing protocols, these protocols are not unicast. Finally, in order to improve the connectivity in dynamic VANETs, new interference-aware routing protocols are considered by the researchers [36], [37]. The connectivity in VANETs can be lost because of shadowing of large vehicle in front of any small vehicle on the road and hence resulting in small coverage area. These protocols use the benefits of dynamic allocation of DSRC spectrum for reducing the interference among the nodes and help in enlarging the coverage area. In the paper, we have shown all the above mentioned protocols in Figure 3 as below.

As per best of our knowledge, most of the earlier researchers discuss only Topological and Geographical based routing protocols. In the paper, efforts have been made to compile all the routing protocols at one place including opportunistic, information dissemination and Interference-aware routing protocols. In [29], author has discussed only topological based, geographical based and hybrid routing protocol. The authors in the literature [36], [37], [38] have discussed about interference routing protocols but they did not mention about other existing routing protocols in detail. In this paper, we surveyed all the available routing protocols in the area. Despite the existence of so many protocols in the area, there is no standard routing protocol in VANET. There is a need of different protocols in both city and highway scenario. A benchmark tool is also required to evaluate the performance of all these existing and new proposed protocols.

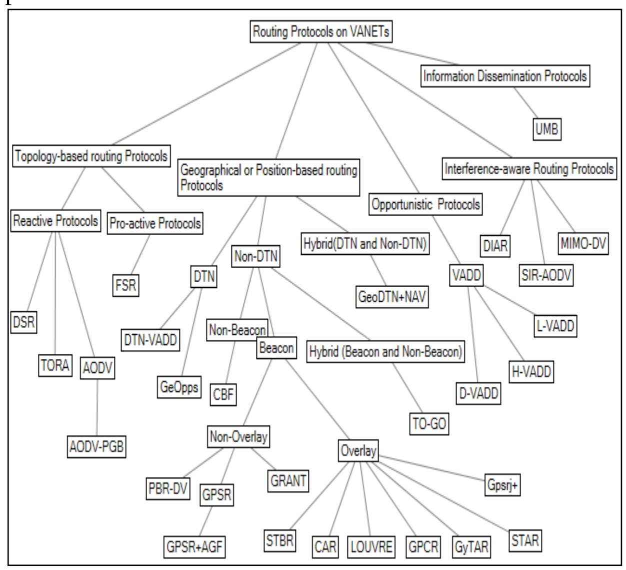


Figure 3 Routing Protocols in VANETs

4.1 Topology-based Routing Protocols

Topology-based routing protocols use links information to forward the incoming packets to next node in the system. This information is stored in the routing table. In vehicular environment, due to the mobility of the vehicles, link information changes very frequently result in route breaks. Topology-based routing protocols are further classified into reactive i.e. on-demand and proactive i.e. table driven routing protocols [35].

4.1.1 Reactive Protocols

Reactive protocols are also known as on-demand protocols and hence help in reducing the congestion and overhead in the network. Whenever there is a requirement, source node starts the network discovery process for new route for the destination and stores the route temporarily [39]. It will stop the discovery process as soon as it gets the route. Problem associated with these protocols is excessive flooding in the network due to messages sent for discovery of a new route, causing overloading of nodes during communication [35].The main reactive protocols used in VANETs are Dynamic Source Routing (DSR), Temporally Ordered Routing Algorithm (TORA) and Ad-hoc On demand Distance Vector (AODV) which is further modified as Preferred Group Broadcasting (AODV-PGB) [1], [40].

DSR is a multi-hop routing protocol that makes use of source routing and maintains the active routes. It does the route discovery and maintenance for self-configuration. It does not work in case of broken links [17]. TORA is a distributed and multi-hop routing protocol based on link reversal routing. Here, start node broadcast the packet to all nodes in the system [31]. The node that has a path to the destination will reply back otherwise packet is dropped. Scalability is the major issue with this protocol. AODV is a demand routing protocol based on backward learning process. Here each node maintains the information of next hop with sequence number and hop count for route discovery process. It does not work efficiently for time critical applications [18]. PGB uses a broadcasting method to reduce the overhead in AODV protocol by sending the message in preferred or non-preferred group at a time [1].

4.1.2 Proactive Protocols

Proactive protocols are also known as table-driven protocols, as they use the routing table to store the information for all other nodes of the network irrespective of the need. Advantage of using these protocols is that there is no need to discover the route and they provide low latency in real time applications. Problem associated with these protocols is of unused path that occupy a significant part of available bandwidth [35]. These protocols are based on shortest path algorithms. The table needs to be updated regularly according to the changes in the network topology and then periodically broadcasted to the other nodes [41]. Fisheye State Routing (FSR) used in VANETs comes in this category [1]. In FSR, each node uses the information about its neighbours to maintain its routing table. FSR aims to reduce the bandwidth requirement by restricting the communication among neighbours only [33]. It works best in small sized networks i.e. with less number of nodes in the system [39]. Problem with this routing protocol is of less knowledge about distant neighbours and hence insufficient information for the establishment of new route.

4.2 Geographical or Position-based Routing Protocols

Geographical protocols are also known as position-based protocols. These protocols use position data of the node along with the position of its neighbours, obtained through GPS or digital maps in making decision about routing in VANETs. These protocols do not require routing tables and hence are suitable for dynamic mobility patterns. Geographical protocols are categorized as Delay Torrent Network (DTN), non-DTN and Hybrid protocols. DTN protocols are designed for the disconnected networks and hence can handle the irregularities in VANETs whereas non-DTN does not consider the irregular connectivity patterns. They are best suitable for dense VANET environments i.e. city scenario. Hybrid geographical routing protocols are designed with the motive of combining the advantages of both DTN and non-DTN routing protocols [12], [31].

4.2.1 DTN Protocols

In DTN protocols, improvement in packet delivery is achieved by allowing nodes to store the packets, when there is no contact with other nodes. This allows them to hold the packets for some distance until the discovery of other neighbouring nodes to which the packets can then be forwarded [42], [43]. VADD and GeOpps are the protocols used in VANETs environment [15]. The aim of VADD routing algorithm is to improve routing decisions in vehicular networks in consideration of various parameters as road distance, average velocity of vehicle and density on roads etc. GeOpps make the use of navigation system to forward the packets while making routing decisions in network [1].

4.2.2 Non-DTN Protocols

The non-DTN protocols follow greedy approach in which a node forwards the packet to its closest neighbour. These protocols suffer from the problem of local maxima. These protocols can further be divided into non-beacon, beacon and hybrid protocols [42], [44].

4.2.2.1 Non-Beacon Protocols

Example of non-beacon protocol is Contention-Based Forwarding (CBF) protocol. CBF protocol does not use beacon messages concept rather it makes use of distributed contention process based on biased timers to select the next node. This protocol decreases the packet collision probability in the network [40].

4.2.2.2 Beacon Protocols

Beacon protocols can be further divided into non-overlay and overlay protocols [1].

4.2.2.2.1 Non-Overlay Protocols

The greedy approach is the main principle used by the non-Overlay protocols. Here, a node forwards the packet to its closest neighbours to the destination. Some routing protocols used by VANETs in non-overlay category are Greedy Perimeter Stateless Routing (GPSR) that is modified with Advanced Greedy Forwarding (AGF) protocol, Position-Based Routing with Distance Vector Recovery (PBR-DV) and Greedy Routing with Abstract Neighbour Table (GRANT) [6], [12], [15].

GPSR is suitable for highway environment. Beacon messages are used to update the routing table with the information received by other nodes of the system. GPRS works with greedy forwarding and recovery approach in order to take the routing decision. AGF is designed to use direction and speed of a node in beacon message for the routing decision. PBR-DV uses AODV style recovery to deal with local maximum problem. GRANT makes use of extended greedy routing protocol to find the x-hop neighbour to avoid the problem of local maxima [40].

4.2.2.2.2 Overlay Protocols

When any routing protocol works on a set of selected nodes overlapped on the whole network, it is known as overlay routing protocol. The protocols which come under this category are Greedy Perimeter Coordinator Routing (GPCR), GpsrJ+ with the removal of unnecessary stopping at junctions, Connectivity-Aware Routing (CAR), Geographical Source Routing (GSR), Anchor-Based Street and Traffic Aware Routing (A-STAR), Street Topology Based Routing (STBR), Greedy Traffic Aware Routing protocol (GyTAR) and Landmark Overlays for Urban Vehicular Routing Environments (LOUVRE).

GPCR assumes that the coordinator nodes on junction are responsible for forwarding the data [34]. CAR incorporates location service for route selection process by using beaconing and route recovery mechanism with the help of Guards [42]. GSR combines location and topological information for routing decision. It makes use of Dijkstra's algorithm for shortest path. A-STAR is designed with local recovery approach for city environment to deal with the problem of local maxima. Here, the routes are based on both static and dynamic maps. STBR is based on street maps. GyTAR takes the number of cars per road with respect to roadside units in order to calculate the road connectivity [12]. LOUVRE promises less delay and optimality of global routes. It makes use of vehicular density threshold for the route selection [31].

4.2.2.2.3 Hybrid Protocols (Non-Beacon and Beacon protocols)

These protocols combine the benefits of both Beacon and Non-Beacon protocols in taking the decision for relaying packet by combining the beaconed and non-beaconed approach to tradeoff reliability, robustness and overhead. TOpology-assist Geo-Opportunistic Routing (TO-GO) protocol is an example of hybrid protocol [1], [12], [41]. It uses two-hop beacon information in order to select the forwarding node. Target node is being selected by the recovery or greedy algorithm depending upon the mode in which routing is being operated.

4.2.3 Hybrid Protocols (DTN and Non-DTN protocols)

These protocols combine the benefits of both DTN and Non-DTN protocols to exploit partial network connectivity by including perimeter, DTN and non-DTN mode. These protocol switch from non-DTN mode to DTN mode by estimating the connectivity of the network based on the number of hops a packet has travelled so far, neighbor's delivery quality, and neighbor's direction with respect to the destination. GeoDTN + Nav is a hybrid routing protocol that includes the navigation for judging the quality of the neighbours through Virtual Navigation Interface (VNI) to make the routing decision by protecting the privacy with optimal route [1]. Routing protocols in VANET are designed to handle a special challenge of their dynamic and highly mobile environment. When VANET is sparse and disconnected, GeoOpps protocol is well suited. When the list and location of its neighbours obtained by the node are inaccurate, CAR is most suitable protocol. Hybrid protocols combine the advantages of more than one protocol at the same time [39].

4.3 Opportunistic Protocols

According to researchers [1], [4], a sparse network is formed on roads during late night or early morning hours, whereas a well-connected dense network is formed during rush hours. To overcome this type of irregular connectivity in VANETs, opportunistic routing protocols are used with the carry-and-forward approach. In this approach, when disturbance in the connectivity happens, a node stores a packet in its buffer and waits until connectivity is available [34]. The Vehicle-Assisted Data Delivery (VADD) is a kind of opportunistic protocol that aims at delivering data with the lowest delay. Here, a moving vehicle carries the packet at least until another vehicle enters into its neighbourhood, when the vehicle may forward the packet to the recently arrived neighbor. This protocol uses predictable vehicle mobility to forward the packets. On the basis of the existing traffic patterns, a vehicle can find the next path to forward the packet in order to reduce the delay.

The packet carrier sorts all the outgoing directions and checks if there is a contact available to help forwarding through that direction. However, determining the next hop among all available contacts and ensuring that a packet goes through the precomputed direction is not trivial. Different VADD protocols are proposed in literature [4], [15], [29], [34] to forward the packet to the best road at an intersection. The main protocols are Location first probe-VADD (L-VADD), Direction first probe-VADD (D-VADD) and Hybrid probe-VADD (H-VADD). Given the preferred forwarding direction of a packet, L-VADD tries to find the closest contact toward that direction as the next hop. L-VADD may result in routing loops. Routing loops occur because vehicles do not reach unanimity on the order of priority, and then do not have an agreement on who should carry the packet.

To address this issue, D-VADD ensures that everyone agrees on the priority order by letting the vehicle moving toward the desired packet forwarding direction carry the packet. D-VADD selects the contacts moving toward the selected direction. Among the selected contacts, the one closest to the selected direction is chosen as the next hop. D-VADD gives priority to the moving direction and may suffer from a long packet forwarding distance, and hence long packet delivery delay. H-VADD combines L-VADD and D-VADD. Upon entering an intersection, H-VADD behaves like L-VADD with loop detection. If a routing loop is detected, it immediately switches to D-VADD until it exits the current intersection. To forward data in the straightway mode, a target location (an intersection) is specified and then the geographically greedy forwarding is used.

4.4 Information Dissemination Protocols

Information dissemination is essential to several applications. For example, some driver assistant applications demand the dissemination of information about road conditions, such as traffic, obstacles and hazards. Other applications related to entertainment deliver advertisements and announcements. Therefore, some protocols have been designed to efficiently disseminate information. A subgroup of information dissemination routing protocols corresponds to geocast routing. The objective of a geocast routing protocol is to deliver packets from a source node to other nodes within a specified geographical region, Zone of Relevance (ZOR).

The Urban Multihop Broadcast (UMB) protocol is designed to address the broadcast storm, hidden node and reliability problems of multihop broadcast in urban areas. In this protocol, only one vehicle at a time is responsible for forwarding and acknowledging broadcast packets in the direction of dissemination. Moreover, when there is an intersection in the path of the message dissemination, new directional broadcasts are initiated by repeaters located at the intersections. In a geocast protocol, a network efficient hop-to-hop delivery, also called line forwarding, is applied when the packet is outside the destination region. In such a phase, packet losses can happen when the local maximum is reached and no special strategy is used to overcome this problem [45]. Inside the geocast destination region, hop-to-multihop routing, i.e. flooding, allows the delivery to all nodes of the destination region. The default greedy forwarding process can be used, but it has the effect of frequently selecting next hops that lie close to the relaying node's wireless transmission range border.

4.5 Interference-aware Routing Protocols

Interference is an integral property of wireless networks that determine the spectrum boundaries for reuse. It can directly affect the protocol performance as well as the network capacity. The amount of interference depends on many factors that include spatial node distribution and radio propagation environment. In literature, there exist many approaches to reduce the interference effect, defining routing protocols and interference-aware metrics. These protocols have the possibility of changing the SCH dynamically [46]. There exist DIAR, an interference-aware routing protocol that was based on the path-delay and improves network throughput [47]. Next, SIR-AODV has been proposed in [36], based on the traditional signaling scheme of AODV, which reduces the interference levels among nodes by utilizing the advantage of a dynamic allocation of the DSRC spectrum. Further, in order to improve the connectivity in VANETs, a new interference-aware routing protocol is proposed by authors in [46]. This protocol also uses the benefits of dynamic allocation of DSRC spectrum for reducing the interference among the nodes. The connectivity can be lost because of shadowing. A cooperative retransmission algorithm to overcome this problem is proposed by [37]. It minimizes the interference among the nodes while gain in the coverage area.

5. Challenges and Future Perspectives in Vehicular Networks

The special behaviour and characteristics of Vehicular networks distinguish them from other mobile networks. Vehicular networks have exclusive and distinct characteristics such as: higher computational capability, unlimited transmission power and predictable mobility as compared to other communication networks like MANETs or WANETs. This study will help the researchers in developing standard routing protocols exclusively for VANETs that can work in both cities as well as highway environment. However, vehicular networks needs to cope with some challenging characteristics that may be used for further research in the area as discussed below:

- **Potentially large scale with Data management and storage:** Earlier ad-hoc networks like mobile ad-hoc networks and wireless ad-hoc networks that are studied in the literature normally have a limited network size, whereas vehicular ad-hoc networks can be extended over the entire road infrastructure available therein and also it can include as many as vehicles as participants, that are present on the road at that time [48]. Due to the large scale and millions of vehicles in the vehicular networks, a huge amount of distributed data is being generated. This data needs to be distributed and stored across the VANET in some way. Due to the massive scale in terms of huge produced data, large size of network and the inherent dynamic properties of VANETs, there exist new and unique challenges in the field of both data acquisition and management [49].
- **Network topology, partitioned network and connectivity:** Vehicular networks are distinct from other existing ad hoc networks due to moving vehicles that changes their position continuously and hence resulting in the formation of highly dynamic network. The network topology changes very frequently as the links between nodes connect and disconnect very often and the underlying networks become recurrently partitioned [50]. This dynamic nature of traffic may result in large inter vehicle gaps in sparsely populated environment and hence resulted network remains in several isolated clusters of the nodes. Further, the range of wireless links and the fraction of participant vehicles help in the determining the degree of connectedness in the network [17].

- **High mobility and variable network density:** The vehicular network operates in a very dynamic environment and involves extreme configurations. It may operate either in highway scenario or in the city environment. On highways, relative speeds of vehicles may go up to 200 km/h, while density of nodes may be only 2-3 vehicles per km on the roads which are not very busy. In this case, the VANET is sparser with less connectivity between the nodes. This initiates the need of protocols that must be aware of these disconnections. On the other hand, in the city, relative speeds can reach maximum up to 60 km/h only and node density can be very high, especially during peak hours. So, it is necessary to design protocols for medium access control to avoid collision and transmission errors. The vehicles travelling simultaneously in both scenarios need to adapt their behaviour according to the variations in the network density to provide a good data transfer [38], [51].

- **Security and privacy:** The network security issues in VANETs are similar to those that exist in the other traditional wireless ad-hoc networks. Though, security challenges in VANETs are fundamental and unique due to the frequent topology changes, size of the network, high mobility patterns, and the different classes of applications and services, with conflicting requirements offered to such networks. Besides these challenges, the authentication and non-repudiation versus privacy in the vehicular environment need also to be taken care of [12]. Despite lot of research, the problem of security still exists in VANETs and new secure communication protocols must be investigated taking into consideration the unique characteristics of these heterogeneous vehicular networks [51], [52].

- **Standardization of protocols:** The different types of vehicles such as trucks, cars, trams, buses, taxis motorbikes and bicycles may be involved in the communication at a time in VANETs. So, it is important for the network, that all of these nodes are able to communicate among themselves using the same standard protocol. This can only be achieved when there is a regularization of standards and protocols with simultaneous efforts involving industry, government and academia together [38], [52].

- **Disruptive tolerant communications:** In case of sparse networks, there exist the problem of lower reliability, late delivery and higher delay. To enable the fast delivery and reliability, there are some solutions that make use of Carry-and-Forward technique that can increase the total information delivery time. These problems can be minimized or solved by exploring new data communication approaches especially designed for the heterogeneous vehicular ad-hoc networks. The driver's behaviour can be considered as an alternative to improve the carry-and-forward method and hence can reduce the information delivery time [53], [54].

- **Cooperation with other networks:** In VANETs, the nodes are expected to interact with other nodes, infrastructure and various other applications and services which exist in the network. To provide a good service to the user, the cooperation between these nodes is required in order to provide the information about current weather, traffic conditions and routes available. This information can be acquired through interactions among sensor networks, WANs, LANs and Internet [55].

- **Need of benchmark for testing:** The vehicular ad hoc network is highly mobile and dynamic. Thus, network is partitioned that keeps on changing. At times the network may be sparse or dense; the same protocol may not work efficiently in this environment [38], [51]. There is a need for some standard protocols which perform efficiently in all scenarios. Further there is no benchmark existing in literature to the best of our knowledge for testing the performance of new proposed protocols in the area.

- **Localization systems and Geographical addressing:** The geographic region or the physical position of a vehicle is necessary for multiple applications requiring a geographical address that can perform data communication. Using the vehicle's mobility pattern and driver's behaviour, it is possible to predict the future position of a vehicle. But this problem to track and manage the geographical addresses by the vehicles or the applications is extremely challenging. VANETs require more reliable and high accurate localization systems to provide critical safety applications. A regular solution in a localization system for VANETs is to embed a GPS receiver in each vehicle. A ubiquitous and reliable localization system may be used by the vehicles in a VANET for emergency and critical safety applications. This all can be offered by a combination of various data fusion with data processing techniques [55], [56].

6. Summary

A comprehensive survey on the development of communication standards, routing protocols and major challenges for Vehicular Ad hoc NETworks (VANETs) is presented in this paper. VANET is a subclass of Wireless Ad hoc NETworks (WANETs) that provides a promising approach for future intelligent transportation system (ITS). These networks have no fixed infrastructure and instead rely on the vehicles themselves to provide network functionality. However, due to mobility constraints, driver behavior, and high mobility, VANETs exhibit characteristics that are significantly different from the MANETs. This paper presents a systematic difference between the two networks.

In the past decade, many VANET projects around the world have been undertaken and several VANET standards have been developed to improve vehicle-to-vehicle or vehicle-to infrastructure communications. In this paper, we reviewed some of the main areas that researchers have focused on in the last few years and these including cellular access, DSRC, WAVE and WiMAX and emphasized the most salient results achieved till date by them. The upcoming new technology of 4G cellular access for VANET has also been discussed in the present study.

Routing in VANETs is different from the routing in MANETs as vehicles can move only on pre-set roads. A complete taxonomy of various existing routing schemes with their relative advantages and disadvantages of each other is presented in this study. The details of existing routing protocols along with their detailed analysis for MANETs that are used in VANETs and the protocols used specifically for the vehicular environment, i.e., Opportunistic, Information dissemination and Inference-aware routing protocols are included in the paper.

We provide a comprehensive list of challenges exist in VANETs with the current state of the research and future perspectives in order to enable the deployment of VANET technologies, infrastructures, and services cost-effectively, securely, and reliably. Updated standards and routing protocols for VANETs along with the challenges and future perspectives all at one place are presented in the paper. This study will enable researchers to have a thorough understanding of VANETs, its standards and routing protocols so that they can focus on the current research trends along with the future direction in this area.

References

[1] Mohamed Watfa, *Advances in Vehicular Ad-Hoc Networks: Developments and Challenges*.: IGI Global, 2010.

[2] Ganesh S. Khekare and Apeksha V. Sakhare, "Intelligent Traffic System for VANET: A Survey," *International Journal of Advanced Computer Research*, vol. 2, Number-4, no. 6, pp. 99-102, December 2012.

[3] Rakesh Kumar and Mayank Dave, "A Review of Various VANET Data Dissemination Protocols," *International Journal of u- and e-Service, Science and Technology*, vol. 5, no. 3, pp. 27-44, 2012.

[4] Sherali Zeadally, Ray Hunt, Yuh Shyan Chen, Angela Irwin, and Aamir Hassan, "Vehicular ad hoc networks (VANETS): status, results and challenges," *Springer Science, Business Media, LLC*, p. 25, 2010.

[5] Manjot Kaur, Sukhman Kaur, and Gurpreet Singh, "Vehicular Ad Hoc Networks," *Journal of Global Research in Computer Science*, 2012.

[6] Prassant Mohapatra and Srikanth V. Krishnamurthy, *Ad Hoc Networks : Technologies and Protocols*. Boston, USA: Springer, 2005.

[7] Mohammad Jalil Piran, G. Rama Murthy, and G. Praveen Babu, "Vehicular Ad Hoc and Sensor Networks; Principles and Challenges," *International Journal of Ad hoc, Sensor & Ubiquitous Computing (IJASUC)*, vol. 2, no. 2, pp. 38-49, 2011.

[8] C K Toh, *Ad Hoc Mobile Wireless Networks*.: Prentice Hall Publishers, 2002.

[9] Francisco J. Martinez, Chai Keong Toh, Juan Carlos Cano, Carlos T. Calafate, and Pietro Manzoni, "A survey and comparative study of simulators for vehicular ad hoc networks (VANETs)," *Wireless Communictions and Mobile Computing*, vol. 11, pp. 813–828, 2011.

[10] Punam Bedi and Vinita Jindal, "Use of Big Data Technology in Vehicular Ad-hoc Networks," in *International Conference on Advances in Computing, Communications and Informatics (ICACCI - 2014)*, Greater Noida, India, 2014, pp. 1677 – 1683.

[11] K. R. Jothi and A. Ebenezer Jeyakumar, "Optimization and Quality-of-Service Protocols in VANETs: A Review," *Artificial Intelligence and Evolutionary Algorithms in Engineering Systems*, pp. 275-284, 2015.

[12] Hassnaa Moustafa and Yan Zhang, *Vehicular networks: techniques, standards, and applications*.: Auerbach publications, 2009.

[13] U.S. Department of Transporatation, "Intelligent Transportation System (ITS) Home," january 2014. [Online]. http://www.its.dot.gov/index.htm

[14] Peppino Fazio, Floriano de Rango, and Andrea Lupia, "Vehicular Networks and Road Safety: an Application for Emergency/Danger Situations Management Using the WAVE/802.11p Standard," *Advances in Electrical and Electronic Engineering*, pp. 357-364, 2013.

[15] Yun Wei Lin and Yuh Shyan Chen, "Routing Protocols in Vehicular Ad Hoc Networks: A Survey and Future Perspectives," *Journal of Information Science and Engineering*, vol. 26, pp. 913-932, 2010.

[16] Kartik Pandit, Dipak Ghosal, H. Michael Zhang, and Chen-Nee Chuah, "Adaptive Traffic Signal Control With Vehicular Ad hoc Networks," *IEEE Transactions on Vehicular Technology*, vol. 62, no. 4, pp. 1459-1471, May 2013.

[17] Saif Al-Sultan, Moath M. Al-Doori, Ali H. Al-Bayatti, and Hussien Zedan, "A comprehensive survey on vehicular Ad Hoc network," *Journal of Network and Computer Applications, 37*, pp. 380-392, 2014.

[18] Arzoo Dahiya and R K Chauhan, "A Comparative study of MANET and VANET Environment," *Journal of Computing*, vol. 2, 2010.

[19] Dedicated Short Range Communication (DSRC) Home. (2014, February) [Online]. http://www.leearmstrong.com/DSRC/DSRCHomeset.htm

[20] Y. Kudoh, "DSRC standards for multiple applications," in *11th world congress on ITS Nagoya*, Japan, 2004, pp. 1-19.

[21] Wai Chen, Ratul K. Guha, Taek Jin Kwon, John Lee, and Yuan Ying Hsu, "A survey and challenges in routing and data dissemination in vehicular ad hoc networks," *Wireless Communications and Mobile Computing*, vol. 11, pp. 787–795, 2011.

[22] Sajjad Akbar Mohammad, Asim Rasheed, and Amir Qayyum, "VANET architectures and protocol stacks: a survey," *Communication technologies for vehicles*, pp. 95-105, 2011.

[23] IEEE Std 1455-1999, "IEEE Standard for Message Sets for Vehicle/Roadside Communications," pp. 1-134, September 19 1999.

[24] IEEE Std 1609.1-2006, "Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE) - Resource Manager," , vol., no., pp.1,71, Oct. 18 2006," pp. 1-71, October 2006.

[25] IEEE Std 1609.2-2006, "IEEE Trial-Use Standard for Wireless Access in Vehicular Environments - Security Services for

Applications and Management Messages," , vol., no., pp.0_1,105, 2006," pp. 1-105, 2006.

[26] IEEE Std 1609.3-2007, "IEEE Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE) - Networking Services," , vol., no., pp.1,99, April 20 2007," pp. 1-99, aPRIL 2007.

[27] IEEE Std 1609.4-2006, "IEEE Trial-Use Standard for Wireless Access in Vehicular Environments (WAVE) - Multi-Channel Operation," pp. 1-82, November 2006.

[28] IEEE Std 802.16m-2011, "IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Broadband Wireless Access Systems Amendment 3: Advanced Air Interface," pp. 1-112, May 2011.

[29] Amit Dua, Neeraj Kumar, and Seema Bawa, "A systematic review on routing protocols for Vehicular Ad Hoc Networks," *Vehicular Communications, Elsevier*, vol. 1, no. 1, pp. 33-52, January 2014.

[30] Shilpi Dhankhar and Shilpy Agrawal, "VANETs: A Survey on Routing Protocols and Issues," *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)*, vol. 3, no. 6, pp. 13427-13435, 2014.

[31] Marwa Altayeb and Imad Mahgoub, "A Survey of Vehicular Ad hoc Networks Routing Protocols," *International Journal of Innovation and Applied Studies*, vol. 3, no. 3, pp. 829-846, 2013 July.

[32] Puneet Syal and Talwinder Kaur, "A Study of Routing Protocols for Vehicular Ad-Hoc Networks," *International Journal of Engineering Trends and Technology (IJETT)*, vol. 15, no. 1, pp. 25-29, Sep 2014.

[33] Jagadeesh Kakarla, S. Siva Sathya, B. Govinda Laxmi, and Ramesh Babu B, "A Survey on Routing Protocols and its Issues in VANET," *International Journal of Computer Applications*, vol. 28, no. 4, pp. 38-44, 2011.

[34] Fan Li and Yu Wang, "Routing in Vehicular Ad Hoc Networks: A Survey," *IEEE Vehicular Technology Magazine*, pp. 12-22, 2007.

[35] Bijan Paul and Mohammed J. Islam, "Survey over VANET Routing Protocols for Vehicle to Vehicle Communication," *IOSR Journal of Computer Engineering (IOSRJCE)*, vol. 7, no. 5, pp. 1-9, 2012.

[36] Peppino Fazio, Floriano De Rango, and Cesare Sottile, "An On Demand Interference Aware Routing," *Journal of Networks*, vol. 7, no. 11, pp. 1728-1738, 2012.

[37] Quincy Tse and Bjorn Landfeldt, "Interference-Aware Geocasting for VANET," in *International Symposium on a World of Wireless, Mobile and Multimedia Networks (WoWMoM)*, San Francisco, CA, 2012, pp. 1-6.

[38] Marc Emmelmann, Bernd Bochow, and C. Christopher Kellum, *Vehicular Networking: Automotive Applications and Beyond*. United Kingdom: John Wiley & Sons Ltd., 2010.

[39] Shivani Rana, Swati Rana, and Kamlesh C. Purohit, "A Review of Various Routing Protocols in VANET," *International Journal of Computer Applications*, vol. 96, no. 18, pp. 28-35, June 2014.

[40] Mohamed Ben Ahmed , A. A. Boudhir , M. Bouhorma , and K. Ben Ahmed, "Performance Study of Various Routing Protocols in VANET Case of Study," *International Journal of Future Generation Communication and Networking*, vol. 7, no. 6, pp. 231-240, 2014.

[41] Sabih Ur Rehman, M. Arif Khan, Tanveer A. Zia, and Lihong Zheng, "Vehicular Ad-Hoc Networks (VANETs) - An Overview and Challenges," *Journal of Wireless Networking and Communications*, vol. 3, no. 3, pp. 29-38, 2013.

[42] Bijan Paul, Md. Ibrahim, and Md. Abu Naser Bikas, "VANET Routing Protocols: Pros and Cons," *International Journal of Computer Applications*, vol. 20, no. 3, pp. 28-34, April 2011.

[43] Ramin Karimi, Norafida Ithnin, Shukor Abd Razak, and Sara Najafzadeh, "DTN Routing Protocols for VANETs: Issues and Approaches," *International Journal of Computer Science Issues, IJCSI*, vol. 8, no. 6, No 1, pp. 89-93, November 2011.

[44] Ramin Karimi, Norafida Ithnin, Shukor Abd Razak, and Sara Najafzadeh, "Non DTN Geographic Routing Protocols for Vehicular Ad Hoc Networks," *International Journal of Computer Science Issues, IJCSI*, vol. 8, no. 5, No 3, pp. 86-91, September 2011.

[45] Migue Elias Mitre Campista and Rubinstein Marcelo Gonçalves Rubinstein, *Advanced Routing Protocols for Wireless Networks*.: John Wiley & Sons, 2014.

[46] Peppino Fazio, Mauro Tropea, Fiore Veltri, and Salvatore Marano, "A New Routing Protocol for Interference and Path-Length Minimization in Vehicular Networks," in *75th IEEE Vehicular Technology Conference (VTC Spring)*, Yokohama, 2012, pp. 1-5.

[47] Liran Ma, Qian Zhang, Fengguang An, and Xiuzhen Cheng, "DIAR: A Dynamic Interference Aware Routing Protocol for IEEE 802.11-Based Mobile Ad Hoc Networks," in *Mobile Ad-hoc and Sensor Networks*.: Springer Berlin Heidelberg, 2005, pp. 508-517.

[48] Hannes Hartenstein and Kenneth P. Laberteaux, "A tutorial survey on vehicular ad hoc networks," *IEEE Communications Magazine*, vol. 46, no. 6, pp. 164 - 171, 2008.

[49] Moumena Chaqfeh, Abderrahmane Lakas, and Imad Jawhar, "A survey on data dissemination in vehicular ad hoc networks," *Vehicular Communications, Elsevier*, vol. 1, no. 4, pp. 214-225, October 2014.

[50] Wenshuang Liang, Zhuorong Li, Hongyang Zhang, Shenling Wang, and Rongfang Bie, "Vehicular Ad Hoc Networks: Architectures, Research Issues, Methodologies, Challenges, and Trends," *International Journal of Distributed Sensor Networks*, pp. 1-11, 2014.

[51] Md. Humayun Kabir, "Research Issues on Vehicular Ad hoc Network," *International Journal of Engineering Trends and Technology (IJETT)* , vol. 6, no. 4, pp. 174-179, December 2013.

[52] Patrick I. Offor, "Vehicle Ad Hoc Network (VANET): Safety Benefits and Security Challenges ," *Social Science Research Network*, 2012. [Online]. http://ssrn.com/abstract=2206077

[53] Rezwana Karim, "VANET: Superior System for Content Distribution in Vehicular Network Applications," *Rutgers University, Department of Computer Science, Tech. Rep.*, 2008.

[54] P. Mirchandani and L. Head, "A Real-Time Traffic Signal Control System: Architecture, Algorithms, and Analysis," *Transportation Research Part C: Emerging Technologies*, vol. 9, no. 6, pp. 415-432, December 2001.

[55] Felipe Domingos Da Cunha, Azzedine Boukerche, Leandro Villas, Aline Carneiro Viana, and Antonio A.F. Loureiro, "Data Communication in VANETs: A Survey, Challenges and Applications," ISRN INRIA Saclay., France, RR-8498 ISSN 0249-6399, 2014.

[56] B Smitha Shekar et al., "GPS Based Shortest Path for Ambulances using VANETs," in *2012 International Conference on Wireless Networks (ICWN 2012)*, Singapore, 2012, pp. 190-196.

Vinita Jindal is currently pursuing Ph. D. under the supervision of Dr. Punam Bedi from the Department of Computer Science, University of Delhi. She is working in the area of Vehicular Ad-hoc Network. Earlier, she completed her M.C.A. in 2000 and M.Phil. in 2007. She has been working as an Assistant Professor in Department of Computer Science, Keshav Mahavidyalaya, University of Delhi since 2001.

Punam Bedi received her Ph.D. in Computer Science from the Department of Computer Science, University of Delhi, India in 1999 and her M. Tech. in Computer Science from IIT Delhi, India in 1986. She is an Associate Professor in the Department of Computer Science, University of Delhi. She has about 30 years of teaching and research experience and has published about 200 papers in National/International Journals/Conferences. Dr. Bedi is a member of AAAI, senior member of ACM and IEEE, and life member of Computer Society of India. Her research interests include Vehicular ad-hoc networks, Mobile ad-hoc network, Web Intelligence, Soft Computing, Semantic Web, Multi-agent Systems, Intelligent Information Systems, Intelligent Software Engineering, Intelligent User Interfaces, Requirement Engineering, Human Computer Interaction (HCI), Trust, Information Retrieval and Personalization and Recommender Systems.